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RUNWAY CONFIGURATION MANAGEMENT SYSTEM CONCEPTS.(U)

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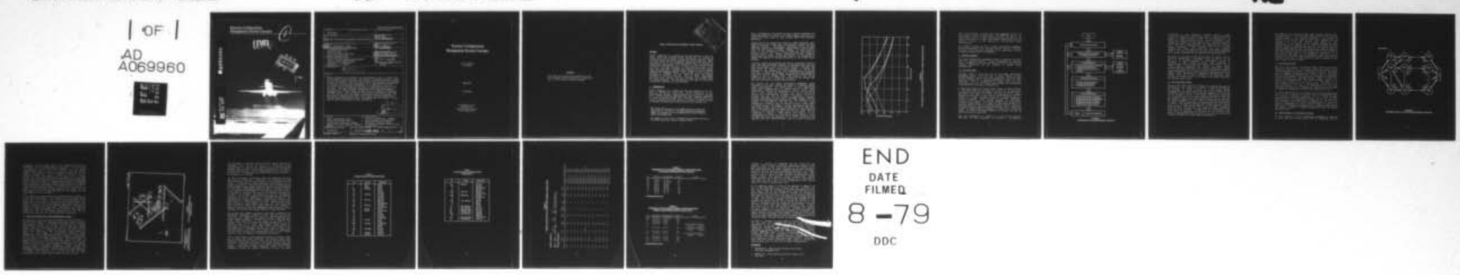

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16. Abstract

Airport congestion is a problem at the busy airports in the U.S. today. Even under moderate growth projections, the problem of increasing delays will worsen at these busy airports, and will spread to other airports which would approach saturation conditions. While long term relief to the congestion problem would be provided by technological improvements, it is essential to fully and efficiently utilize the existing facilities to avoid excessive delays in the near term. This paper addresses the problem of selecting optimal runway configurations to minimize delays through the use of a Runway Configuration Management System. Three concepts of this system are developed to represent the full range of static and dynamic configuration selection processes. The basic model, representing the first level concept, has been developed for Chicago O'Hare International Airport. The application of the model at O'Hare and its possible extensions are also discussed.

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Runway Configuration, FAA, O'Hare International Airport, Airport Delay (reduction), Runway Transition, Airport Capacity (improvement)

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Runway Configuration Management System Concepts

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May 1979

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FOREWORD

This paper was prepared for presentation at the 1979 International Air Transportation Conference, May 1-3, 1979, at New Orleans, Louisiana.

RUNWAY CONFIGURATION MANAGEMENT SYSTEM CONCEPTS

ABSTRACT

Airport congestion is a problem at the busy airports in the U.S. today. Even under moderate growth projections, the problem of increasing delays will worsen at these busy airports and will spread to other airports which would approach saturation conditions. While long term relief to the congestion problem would be provided by technological improvements, it is essential to fully and efficiently utilize the existing facilities to avoid excessive delays in the near term. This paper addresses the problem of selecting optimal runway configurations to minimize delays through the use of a Runway Configuration Management System. Three concepts of this system are developed to represent the full range of static and dynamic configuration selection processes. The basic model, representing the first level concept, has been developed for Chicago O'Hare International Airport. The application of the model at O'Hare and its possible extensions are also discussed.

1. INTRODUCTION

Airport congestion is a problem that the busy airports in the U.S. have to contend with every day. Recent experiences in air transportation indicate a healthy growth in all classes of aviation users. Federal Aviation Administration (FAA) forecasts (Reference 1), based on moderate growth rates, indicate a 25% increase in air carrier operations and a 50% increase in general aviation activity at airports with FAA traffic control service over the next ten

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years. Consequently, the problem of airport capacity limitation and increasing delays will worsen at the busy airports today and will spread in the near future to other airports which face saturation conditions.

Construction of new runways and airports is almost impossible under today's conditions of high costs, environmental concerns and local community pressures. Technological improvements being developed under FAA research and development programs should provide future relief to the congestion problem. However, to avoid excessive delays in the near term and to prevent undesirable restrictions on aviation growth (e.g., quotas, peak-period pricing, mandatory redistribution of traffic to less busy airports), it is essential to improve the capacity of existing facilities to the fullest extent feasible.

Currently, Airport Capacity/Delay Task Forces consisting of aviation users, ATA, FAA and airport sponsors are addressing both short and long term problems at each of the top 10 airports. The Delay Task Force Study for O'Hare International Airport at Chicago was concluded in 1976 (Reference 2). One recommendation of the Chicago Study was to develop and implement an airspace/airfield management plan which utilizes optimal runway configurations (combinations of runways in use) to minimize delay. The potential cost savings associated with such a system was estimated by the Chicago Task Force to be between $11 and $16 million annually.

The concepts for the Runway Configuration Management System discussed in this paper concern the problem of selecting optimal runway configurations. The identification of high capacity/low delay runway configurations is a complex process. Actual runway operations at airports are determined not only by natural factors such as wind, ceiling and visibility, but also by operational factors such as distribution of demand (over routes, over mix of aircraft, over the ratio of arrivals to departures), controller staffing requirements, airport status (equipment outages, pavement closures) and environmental considerations. The complexity of the problem is illustrated by the fact that for a given runway configuration a change in only one variable can have a major impact on aircraft delays. For example, a runway configuration that has a high capacity under a heavy arrival scenario may, on the other hand, have a low capacity when the demand switches to a heavy departure scenario, thus resulting in higher total aircraft delay. This is illustrated in Figure 1 which depicts the capacity of four configurations at O'Hare as a function of percent arrivals. While the high proficiency and experience of air traffic controllers cope admirably with such complex problems, there is a need to provide an

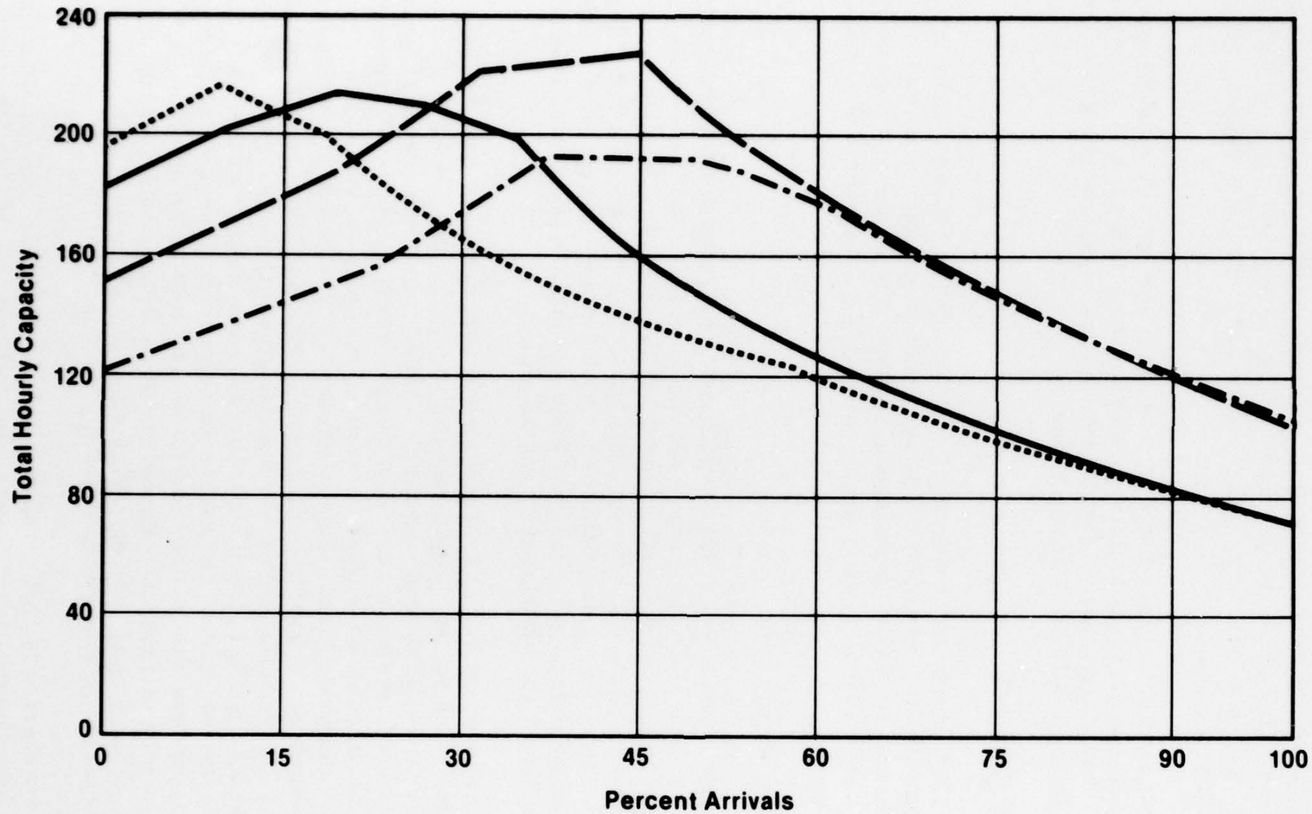

FIGURE 1
VFR CAPACITY CURVES FOR FOUR TYPICAL O'HARE CONFIGURATIONS

aid to the controller to assist him in the consistent selection of high capacity runway configurations. The need for such an aid becomes more acute in a rapidly changing operating environment. The cost effective use of a model for runway configuration selection depends, of course, on the complexity of the available runway configurations.

The proposed concepts for such a runway configuration management system are presented in the following section. Section 3 discusses the models that have been developed as an application of these concepts at Chicago O'Hare International.

2. PROPOSED CONCEPTS

The runway configuration management system is organized into three levels of conceptual models -- basic, intermediate and advanced. Each is designed to build upon the previous level and each provides enhanced capabilities for the selection of optimal runway configurations.

2.1 The Basic Model

The basic model is the first level of the runway configuration management system. Given any set of wind, weather, traffic (arrival/departure ratio) and airport conditions, the basic model provides ordered lists of runway configurations suitable for those conditions. This is accomplished by simply using the given conditions as a series of filters which establish the availability or nonavailability of runway configurations.

A simplified flowchart of the basic model concept is shown in Figure 2. The model begins by updating the current set of operational conditions such as wind and weather. Based on the updated inputs, the model's next step is to check the availability of runways. Runways may be closed to either arrivals and/or departures due to a variety of reasons including excessive crosswind components, tailwind components and/or planned closures for maintenance, construction, or repairs. The current equipment (e.g., glide slope, localizer, middle marker, etc.) status of each runway determines its operating minima as given in published approach charts. Preference of runway operations and runway availability may also be impacted by traffic at nearby airports. Examples of airports with conflicting traffic are O'Hare and Midway Airports at Chicago, and JFK and LaGuardia Airports at New York.

Once the availability of runways for arrivals and departure operations has been determined, an analysis of configuration

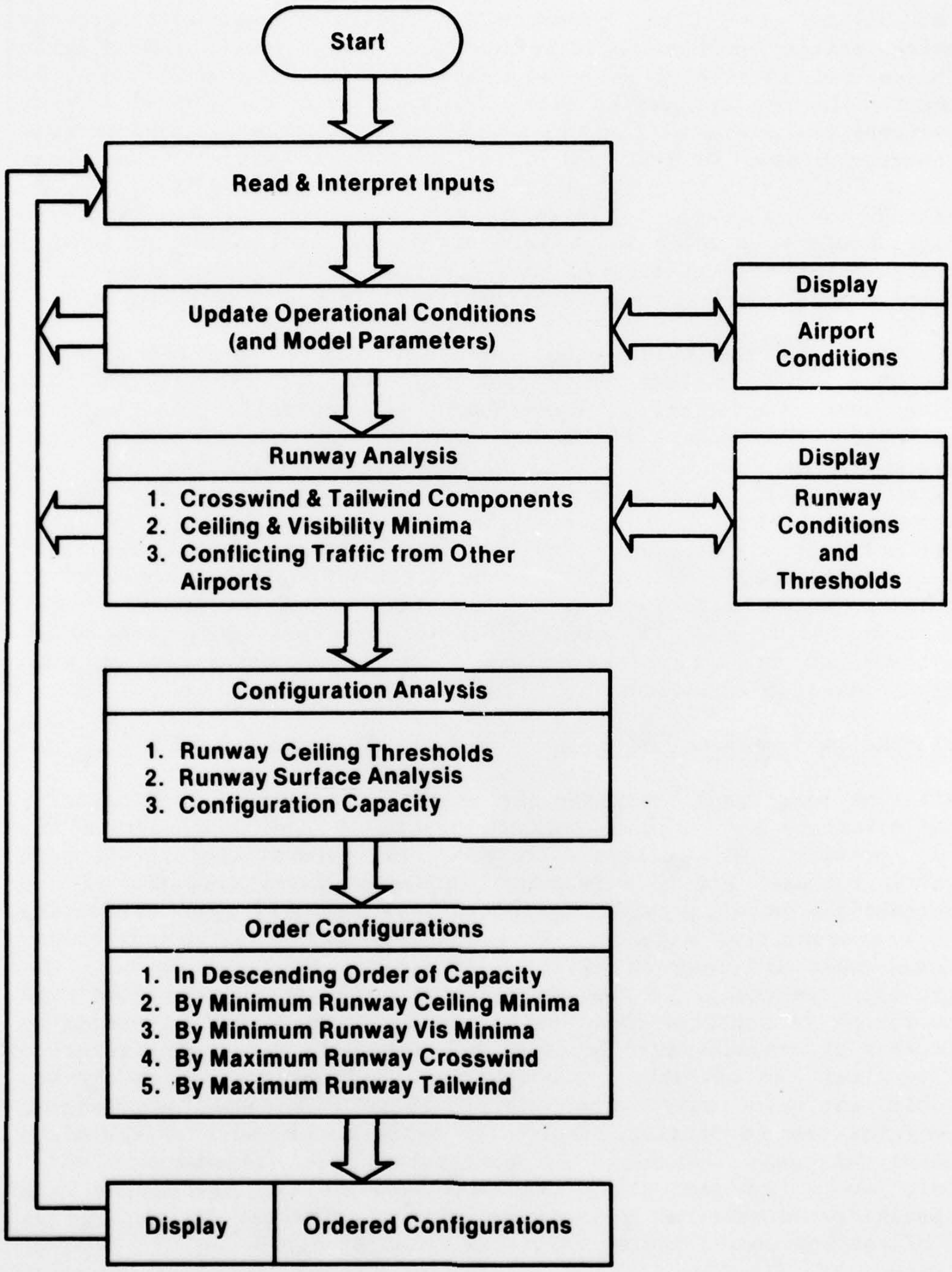

FIGURE 2
OVERVIEW OF THE BASIC MODEL CONCEPT

availability is then conducted. Feasible operating runway configurations based on suitable combinations of remaining available runways are identified from a master list of configurations. In addition to runway availability, other factors considered in the configuration analysis include weather (e.g., intersecting arrival runways not used in IFR conditions) and runway surface conditions (e.g., "hold short" configurations not used under wet or poor braking conditions). The capacities for the candidate configurations -- those which pass all the filters based on updated inputs -- are then calculated as a function of the arrival/departure ratio, weather conditions and the applicable ATC operating rules.

The output of the basic model would provide an ordered list of available configurations in decreasing order of capacity for the given set of operating conditions. Conceptually, it may be desirable to have additional second level orderings of configurations based on other operational considerations such as lowest runway ceiling/visibility minima or lowest runway crosswind/tailwind components. The ordered configuration display will not only assist the controller in selecting the best available runway configuration but will also explicitly identify the extent of capacity losses associated with nonoptimal configurations. Other displays would also be made available to the controller which indicate the current status of the airport and runways along with any operating restrictions.

2.2 The Intermediate Model

While the basic model provides the means for selecting high capacity configurations for a given set of inputs, it does not address the key problem of delays created by transitioning between configurations. For this reason, the second level concepts of the intermediate model provide the additional capability of accounting for the transition effects. This enables configuration selections to be based not only on existing conditions but also on both the next expected change in the operating environment and the time when the change is expected to occur. This is accomplished by assessing the loss of capacity associated with changing from one configuration to another. An operating strategy that includes transition effects should result in lower overall delays in an environment of changing scenarios than a strategy that only optimizes runway configuration choice for each scenario. In particular, the intermediate model would assist in preventing the selection of two successive high capacity configurations whose transition penalty may be so high as to offset the sum of their individual delay benefits.

The output of the intermediate model would identify feasible pairs of configurations -- one for current conditions and one for the next expected change in the operating conditions -- and provide an ordered list of such pairs based on their "total capacity" over the planning period. The total capacity would consist of three components: (1) the capacity of the feasible configuration under existing conditions extended over the time period until the next expected change in operating conditions, (2) the capacity impact of transitioning between the pair of configurations under the expected operating conditions during transitioning, and (3) the capacity of the second configuration for its duration of operation. It is expected that the output of the intermediate model would aid the controller in selecting runway configurations which would minimize aircraft delays over a longer period of time as opposed to the static output of the basic model.

2.3 The Advanced Model

The third level concept, the advanced model, provides the highest degree of sophistication. This model extends the concept of the intermediate model to produce configuration selection "strategies" over an extended time period (e.g., a controller shift). This model utilizes "mimimum cost/maximum flow" network logic to incorporate both predicted changes in the operational environment and transition effects throughout the planning horizon. Figure 3 depicts the concept of the advanced model. The planning horizon consists of 'n' time frames indicated by t_1, t_2, ..., t_n. The nodes of the network consist of sets of 'M' configurations. Each link $(i,j)_k$ from configuration i at time t_k to configuration j at time t_{k+1} represents the capacity of configuration i and the transition effect of changing to configuration j in the time period $(t_{k+1} - t_k)$.

In actual applications of this concept, the list of configurations under t_k will be limited to only the feasible configurations under the predicted operating conditions at t_k. These feasible configurations will be determined through the logic of the basic model applied to the expected set of inputs at t_k. The links will then be defined from each feasible configuration i at t_k to each feasible configuration j at t_{k+1}. With the network so defined, an application of "minimum cost/maximum flow" technique would provide the optimal strategy of runway configurations over the entire planning horizon.

2.4 Relationships of the Proposed Concepts

The three concepts of runway configuration management are designed to build upon the previous model with an increasing level of

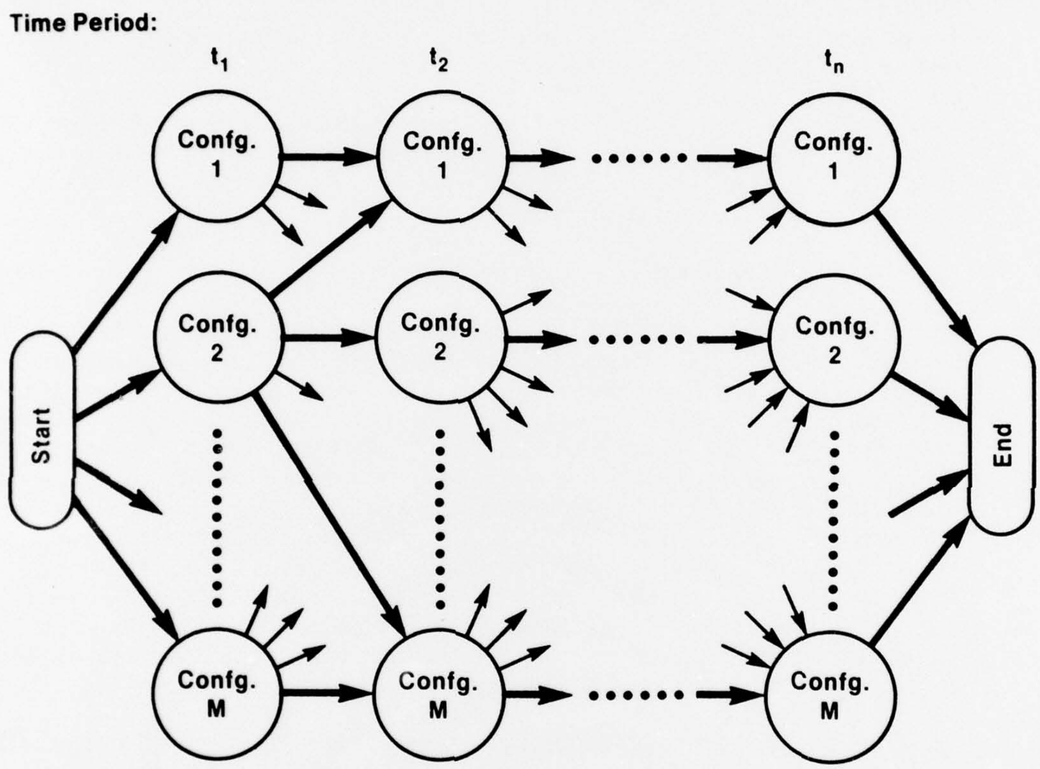

FIGURE 3
NETWORK LOGIC OF THE ADVANCED MODEL CONCEPT

complexity. The basic model provides the foundation on which the intermediate and the advanced models can be built. The basic model is essentially a static model which provides a list of ordered configurations based on one set of inputs. The basic model, however, can be used in an iterative manner to provide two lists of ordered configurations, and a subjective evaluation of the transition effects can provide a first step toward a dynamic system. The intermediate model may be considered as a short range dynamic model which accounts for two sets of operating conditions and the transition effects of changing configurations. The advanced model represents a long range dynamic model providing an optimal runway configuration strategy over the planning horizon (a shift or a day) based on predicted inputs. In terms of the illustration in Figure 3, the basic model is represented by one column (i.e., one time frame only), the intermediate model by two columns, and the advanced model by all n columns.

As the complexity of the model and the planning horizon increase, so do the data requirements. The conclusions of any dynamic model would only be as good as the quality and reliability of the predictions of the inputs. A poor set of predicted inputs could result in a poor choice of operating strategies which may, in turn, produce undesirable results including unnecessary configuration changes or lower delay reductions. Consequently, the level and complexity of model development for specific applications should be guided not only by the design objectives but also by the availability and the quality of the input data requirements.

3. MODEL DEVELOPMENT FOR O'HARE INTERNATIONAL AIRPORT

The findings of the Delay Task Force Study for O'Hare (Reference 2) provided the impetus for developing operational models based on these concepts. Figure 4 represents the runway layout for O'Hare International Airport, the world's busiest and most complex airport. There are twelve main runway ends at O'Hare and a short runway 18/36 which is occasionally used only for small aircraft under visual conditions. With the available runway complex at O'Hare, a large number of operationally feasible runway configurations can be formulated and used. Currently, the assistant chief on duty at the O'Hare facility has the primary responsibility for the selection of runway configurations. The actual choice is normally based on a team effort with participation by tower and TRACON team supervisors. The selection is based on a wide variety of inputs such as wind, weather, demand distributions over approach fixes, controller staffing requirements, runway closures and equipment outages, operations at nearby airports such as Midway, and environmental considerations. A brief analysis of O'Hare operations in January 1978 indicated the use of from one to eight configurations in a single twelve hour period (8 a.m.-8 p.m.).

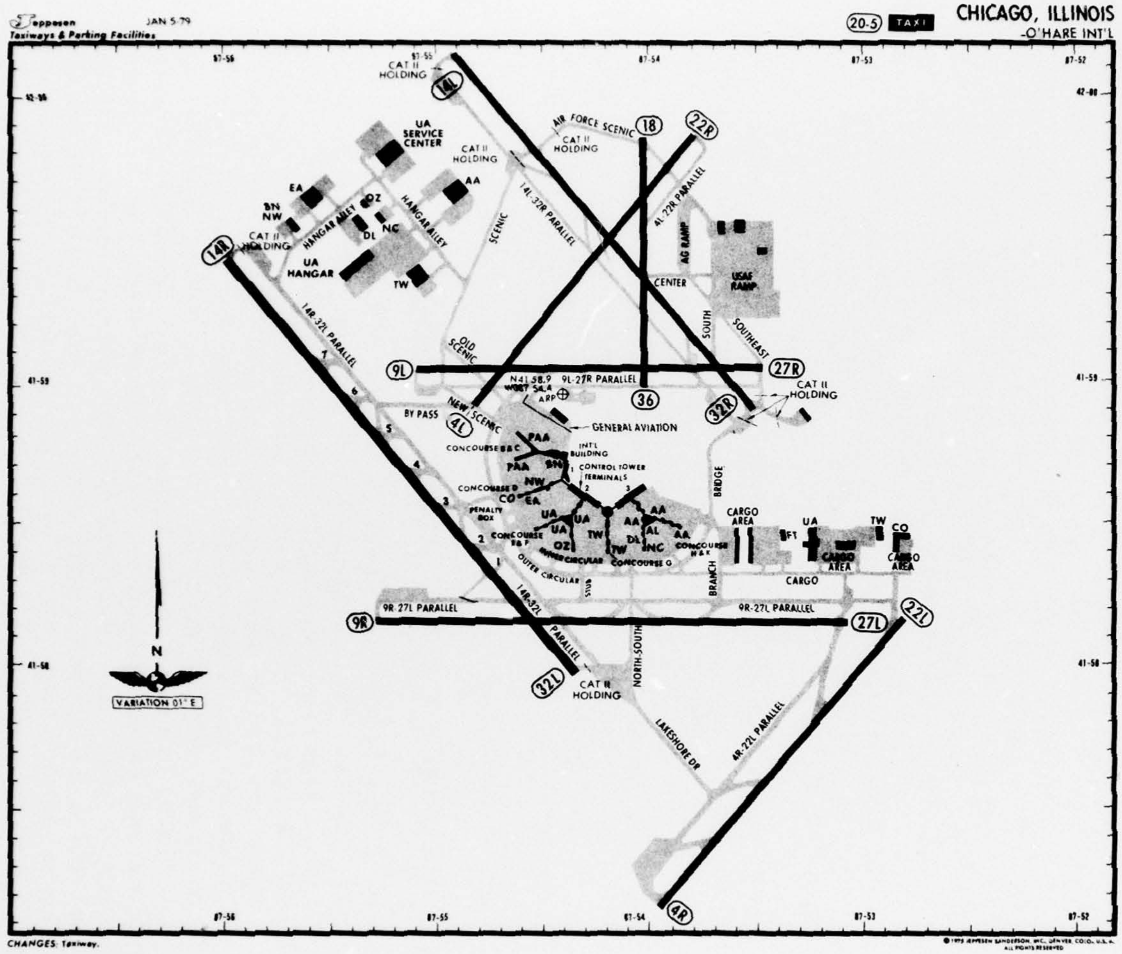

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FIGURE 4
CHICAGO O'HARE INTERNATIONAL AIRPORT LAYOUT

The development of the basic model for O'Hare closely followed the conceptual logic outlined in Section 2. Forty-eight runway configurations of interest were identified by the operational and planning staff of O'Hare and the Great Lakes Region of the Federal Aviation Administration. These configurations, shown in Table 1, were used as a starting point with future additions and deletions to be incorporated as required.

The data requirements of the basic model are categorized as fixed and variable. Fixed data is implicit in the algorithm requiring update only when there are major changes in the operations of the airport. Included in the fixed data bases are the master list of runway configurations, runway characteristics such as landing minima and instrument landing system categories, and the capacity estimates for each runway configurations based on today's air traffic control rules, regulations and procedures. It should be noted that while it is possible to calculate the capacity of feasible configurations on-line, it was decided to precalculate and store the configuration capacities for the full spectrum of arrival/departure mix and both instrument and visual meterological conditions of weather. The precalculation of capacities provided a faster response time for the model which is a critical factor in its use. From an on-line model user's viewpoint, these implicit data bases are fixed within the model and do not require any inputs from the user. However, a separate interactive data base management system program is being developed to facilitate any changes required in these data bases.

The variable data elements are those which require updating in an operational environment. Examples of such data are ceiling and visibility, wind magnitude and direction, arrival/departure mix, runway equipment outages, and approaches to Midway runway 13R which affect O'Hare operations. In the future, it is expected that variable inputs will be provided and updated automatically. In the meantime, users of the model must manually input changes in operational conditions. Hence, human factor considerations have been emphasized in designing both the user inputs as well as the displayed outputs of the model. For instance, the user communicates with the model by means of a conversational style of input in which linguistic codes are combined into English style phrases.

Table 2 shows samples of model-generated displays depicting a given set of airport and runway conditions. The airport display gives conditions affecting the overall airport such as wind velocity, wind direction, ceiling and visibility. The runway display gives the status of conditions affecting each runway including equipment outages, corresponding runway operating minima, actual wind components, surface and braking conditions, as well as runway

TABLE 1
O'HARE RUNWAY CONFIGURATIONS

ID	Arrival	Departure
1	4R/4L	9R/9L
2	9R/9L	4R/4L
3A	14R/14L	9R/9L
B		9L/27L
C		22L/27L
4A	22R/22L	27L/32R
B		27L/32L
C		27R/27L
5A	27R/27L	32R/32L
B		32L/22L
C		32R/32L/22L
6A	32R/32L	27L/32R
B		32R/32L/27L
7	9L/4R	4L/9R
8A	9R/4R	32R/4L/32L
B		9L/4L
C		4L/32R
D		32R/32L
E		9L/4L/32R
9A	14L/9R	4L/9L
B		4R/4L
10A	14R/9R	14L/9L/22L
B		9L/22L
C		9L/4L
11A	14R/22R	22L/27L
B		9L/27L
12	14L/22L	27R/27L
13	14R/22L	22L/27L

TABLE 1
O'HARE RUNWAY CONFIGURATIONS
(CONTINUED)

ID	Arrival	Departure
14A	22R/27L	27R/22L
B		32L/22L
C		32R/32L/22L
D		32L/27L
15A	32L/27R	32R/27L
B		32R/27L/32L
16A	9R/9L/4R	4L/32R
B		32R/32L/4L
C		4L/9R
17A	14L/14R/9R	22L/9L
B		4R/4L
C		9R/9L
18	9R/14R/22R	22L/9L
19	14L/14R/22L	22L/27L
20	22R/22L/14R	22L/27L
21	27R/27L/22R	22L/32L
22A	32L/27R/27L	32R/32L
B		32R/27L
23	32L/27R/22R	32R/32L/27L
24	14R/22R/27L	22L/27L

TABLE 2
SAMPLE DISPLAYS OF AIRPORT AND RUNWAY CONDITIONS

Airport Conditions:

CEIL	VIS	WIND MAG	WIND DIR	MID-WAY?	PCT ARR	RUNWAYS CLOSED			
700.	1.50	5.	220.	NO	50.	14L	ARR	32L	ARR

Runway Conditions:

ID	EQUIP OUT	CAT II	MIN CEIL	MIN VIS	CROSS WIND	TAIL WIND	SUR-FACE	BRAK-ING	RUNWAY CLOSED DUE TO:
4R	NONE	N/A	200.	.50	0.	5.	DRY	GOOD	ARRIVAL : OPEN DEPARTURE : OPEN
4L	NONE	N/A	400.	.75	0.	5.	DRY	GOOD	ARRIVAL : OPEN DEPARTURE : OPEN
9R	NONE	N/A	200.	.50	0.	5.	DRY	GOOD	ARRIVAL : OPEN DEPARTURE : OPEN
9L	NONE	N/A	200.	.50	0.	5.	DRY	GOOD	ARRIVAL : OPEN DEPARTURE : OPEN
14R	NONE	UP	100.	.25	5.	0.	DRY	GOOD	ARRIVAL : OPEN DEPARTURE : OPEN
14L	RLS	DOWN	200.	2.00	5.	0.	DRY	GOOD	ARRIVAL : VISIBILITY DEPARTURE : OPEN
22R	NONE	N/A	200.	.50	0.	0.	DRY	GOOD	ARRIVAL : OPEN DEPARTURE : OPEN
22L	GS	N/A	400.	.50	0.	0.	DRY	GOOD	ARRIVAL : OPEN DEPARTURE : OPEN
27R	NONE	N/A	200.	.50	4.	0.	DRY	GOOD	ARRIVAL : OPEN DEPARTURE : OPEN
27L	NONE	N/A	200.	.50	4.	0.	DRY	GOOD	ARRIVAL : OPEN DEPARTURE : OPEN
32R	NONE	N/A	200.	.50	0.	5.	DRY	GOOD	ARRIVAL : OPEN DEPARTURE : OPEN
32L	NONE	N/A	200.	.50	0.	5.	DRY	GOOD	ARRIVAL : CLOSED DEPARTURE : OPEN

TABLE 3
ORDERED LIST OF ELIGIBLE RUNWAY CONFIGURATIONS
(FOR CONDITIONS DEPICTED IN TABLE 2)

ID	ARRIVALS	DEPARTURES	CAPACITY*	FLAGS
4B	22R 22L	27L 32L	119	
5C	27R 27L	22L 32R 32L	118	
5B	27R 27L	22L 32L	117	
5A	27R 27L	32R 32L	117	
4C	22R 22L	27R 27L	116	
4A	22R 22L	27L 32R	116	
2	9R 9L	4R 4L	104	
1	4R 4L	9R 9L	103	

***In Operations per Hour**

TABLE 4
ORDERED LIST OF ELIGIBLE RUNWAY CONFIGURATIONS
(SAME CONDITIONS AS TABLE 2 EXCEPT VFR)

ID	ARRIVALS	DEPARTURES	CAPACITY*	FLAGS
16B	4R 9R 9L	4L 32R 32L	203	
21	22R 27R 27L	22L 32L	198	
18	9R 14R 22R	9L 22L	197	
17A	9R 14R 14L	9L 22L	191	14L INELIGIBLE BETWEEN SUNSET – SUNRISE
19	14R 14L 22L	22L 27L	182	14L INELIGIBLE BETWEEN SUNSET – SUNRISE
20	14R 22R 22L	22L 27L	180	
17B	9R 14R 14L	4R 4L	175	14L INELIGIBLE BETWEEN SUNSET – SUNRISE
24	14R 22R 27L	22L 27L	167	
16A	4R 9R 9L	4L 32R	164	
16C	4R 9R 9L	4L 9R	163	

***In Operations per Hour**

closures for arrivals or departures and the reason for the closures. Table 3 shows the ordered configuration output of the model associated with the inputs indicated in the previous table. The output shows the top runway configurations and their respective capacities for the given set of operating conditions. The 'flags' column is reserved for operational warnings and restrictions. Note that the list is limited to eight available configurations because O'Hare operates only parallel arrival streams under weather conditions where the ceiling is below 800 feet or the visibility is less than 2.0 nmi. The top six configuration have similar capacities (within 3 operations per hour).

If the operating scenario in Table 2 was expected to change in an hour to VFR conditions (e.g., ceiling 1100 feet, visibility 3.5 nmi), the ordering and the number of available configurations would also change. The top ten configurations under the new set of weather conditions are shown in Table 4. Had the top configuration been chosen in each case, the total capacity for two hours would be 322 minus the capacity loss in transitioning from configuration #4B to #16B. This selection strategy would involve changing arrival streams from runways 22R and 22L to runways 4R, 9R and 9L. The impact of changing the arrival stream from the northeast to one from the west is severe even under moderate traffic loads. A better choice would be to select #5C and #21 respectively, which yields a two hour capacity of 316 operations. Although the capacity difference between the two selection strategies is 6 operations, the latter selection has no transition penalty because the traffic flow remains virtually unchanged. This example illustrates the iterative use of the basic model combined with a subjective evaluation of the transition effect to obtain a better operating strategy.

The model is currently in a test phase at O'Hare. [illegible] the test phase will determine the specific modificati[illegible] enhancements to the basic [illegible] well as further development toward the intermediate and advanced [illegible] Some areas of enhancements include int[illegible]ith vortex [illegible]isory systems, generation of equipment logs, and identification of [illegible]ationships between dual and triple arrival configuration[illegible] to [illegible] in transitions between them. Conceptually, this model ca[illegible] e[illegible] to interact with future equipment monitoring systems and weather data systems to an extent which would require minimal, if any, user input and which would continually update inputs to provide the decision maker with a current list of ordered configurations.

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